Laboratory Evaluation

PurpleAir PA-II PM Sensor

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

Three **PurpleAir PA-II** sensors that were previously evaluated for their performance in the field (deployment period: 12/08/2016 to 01/26/2017) under ambient environmental conditions, have now been evaluated in the SCAQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, temperature, and relative humidity.

PurpleAir PA-II (*3 nodes tested*):

- Particle sensors (optical; non-FEM) (model PMS 5003; *two identical sensors per node)*
- Each sensor reports: PM_1, $PM_{2.5}$, PM_{10} mass concentration ($\mu g/m^3$)
- Time resolution: 35-sec
- Unit cost: ~$200
- Units IDs: Node #1 (8464a, 8464b); Node #2 (cc53a, cc53b); Node #3 (d688a, d688b)

GRIMM (*ref. method for PM_1 and $PM_{2.5}$ mass*):

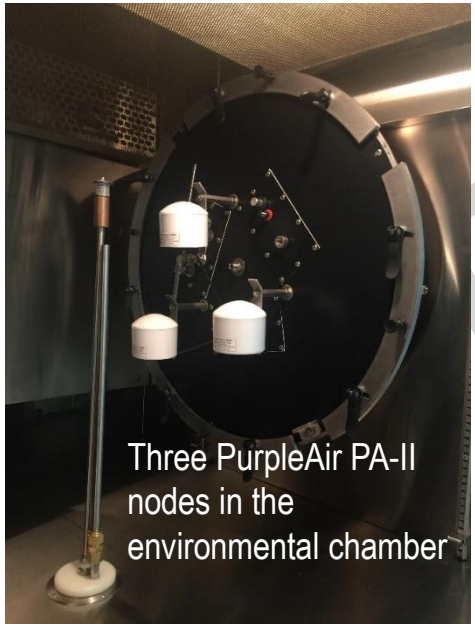
- Optical particle counter
- FEM $PM_{2.5}$
- Uses proprietary algorithms to calculate PM_{10}, $PM_{2.5}$, and PM_1 mass conc. from particle number measurements
- Cost: ~$25,000

TSI APS 3321 (*ref. method for PM_{10} mass*):

- Aerodynamic particle sizer
- Measures particles from 0.5 to 20 µm
- Uses a patented, double-crest optical system for unmatched sizing accuracy
- Cost: ~$50,000

Evaluation results guideline

- PurpleAir PA-II *vs* GRIMM PM_1 mass concentration
- PurpleAir PA-II *vs* GRIMM $PM_{2.5}$ mass concentration
- PurpleAir PA-II *vs* APS *vs* GRIMM PM_{10} mass concentration


Three PurpleAir PA-II nodes in the environmental chamber

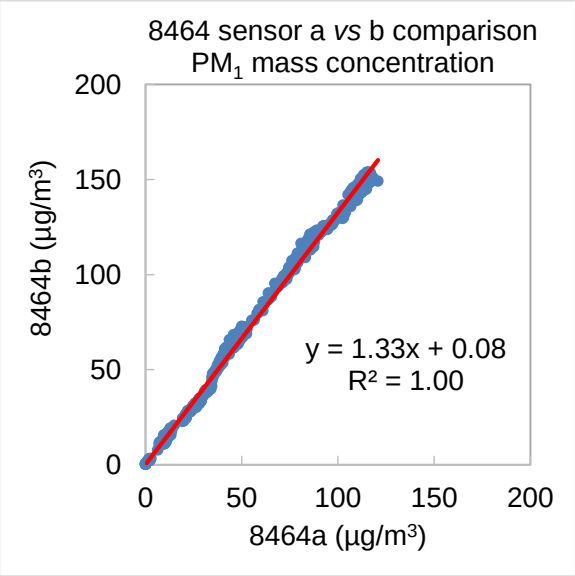

GRIMM

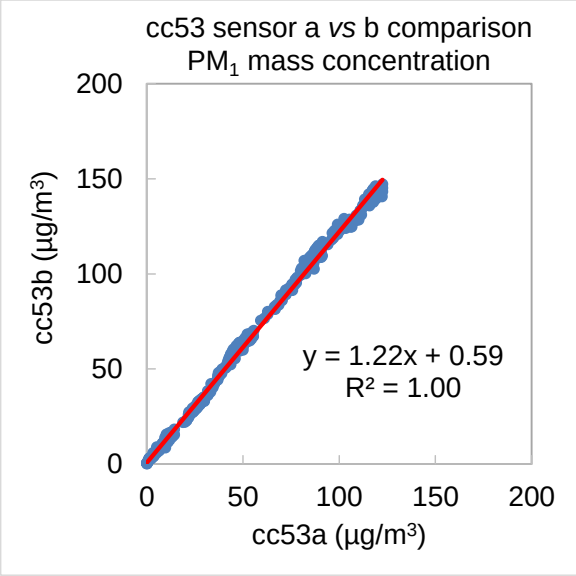
TSI APS 3321

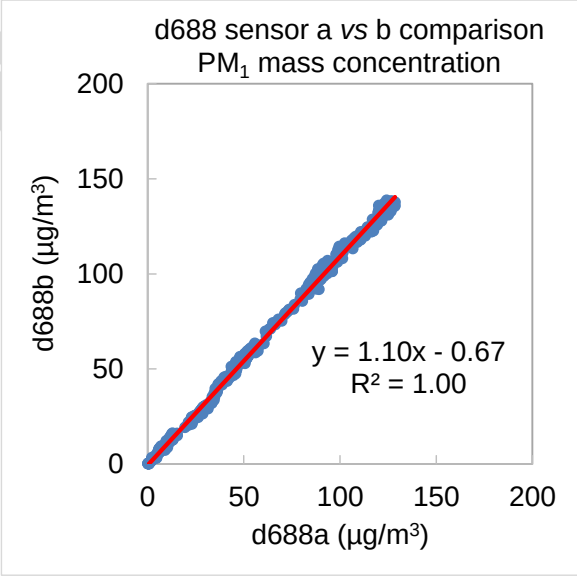
Evaluation results for PurpleAir PA-II PM_1 mass concentration

PurpleAir PA-II vs GRIMM

sensor *a* vs *b* comparison

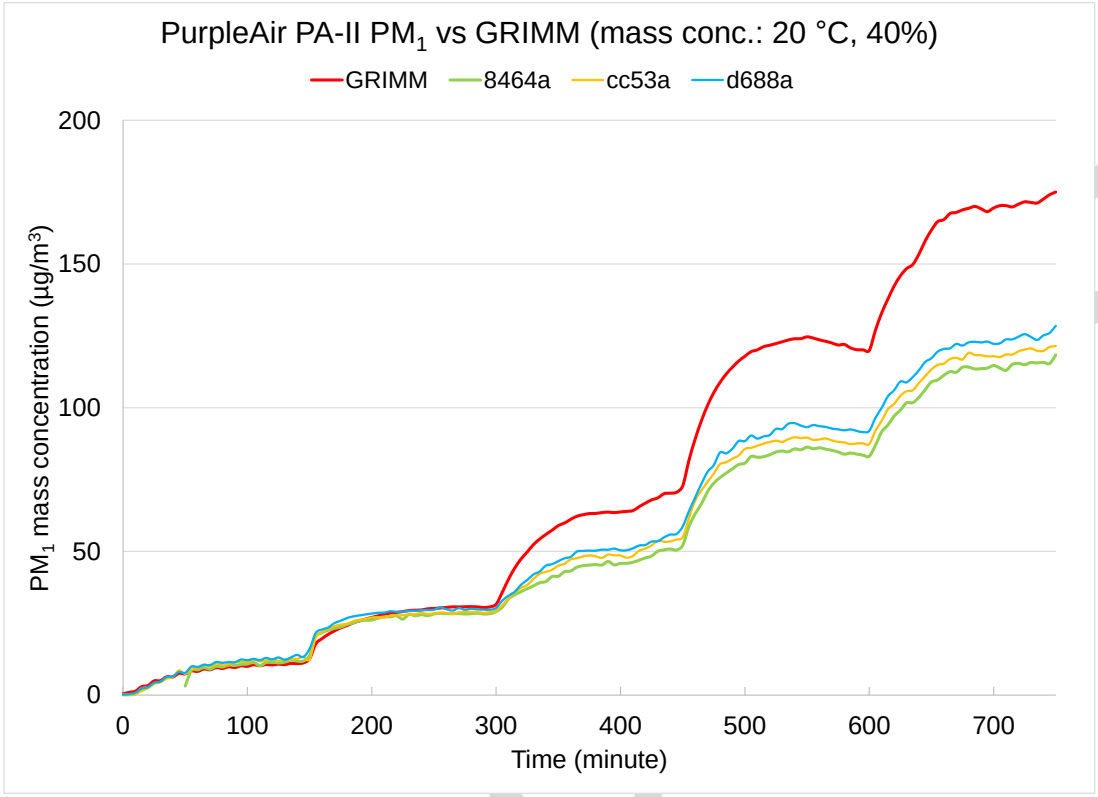






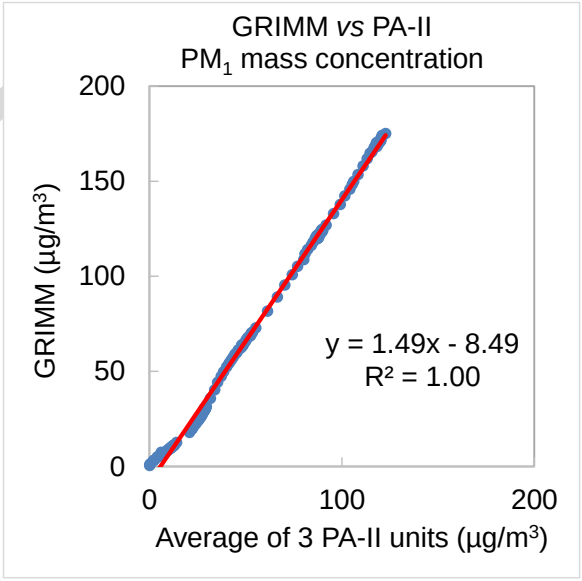
- Each PurpleAir PA-II nodes contains two identical raw sensors, denoted *a* and *b*. For a PM concentration ramping experiment, sensor *a* and sensor *b* had excellent linear correlation with $R^2 > 0.99$.
- However, sensor *b* reported 10-33% higher PM_1 mass concentration than sensor *a* did.
- In order to strictly follow the AQ-SPEC laboratory evaluation protocol, only data from the three *a* sensors is considered in determining evaluation parameters.

PA-II vs GRIMM (PM_1 mass; 5-min mean)



- Over the full PM_1 concentration range tested (0-175 µg/m^3), the three PA-II sensors tracked well with the concentration variation recorded by GRIMM.

Coefficient of Determination



- PA-II sensors showed excellent linear correlation with GRIMM PM_1 mass conc. ($R^2 > 0.99$) between 0-175 µg/m^3.
- PA-II sensors underestimated the GRIMM PM_1 mass conc.

PM_1 Accuracy: PA-II vs GRIMM

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean ($\mu g/m^3$)	GRIMM ($\mu g/m^3$)	Accuracy (%)
1	12.6	11.0	85.2
2	29.0	30.7	94.5
3	53.0	69.8	76.0
4	87.9	120.8	72.7
5	120.5	172.6	69.8

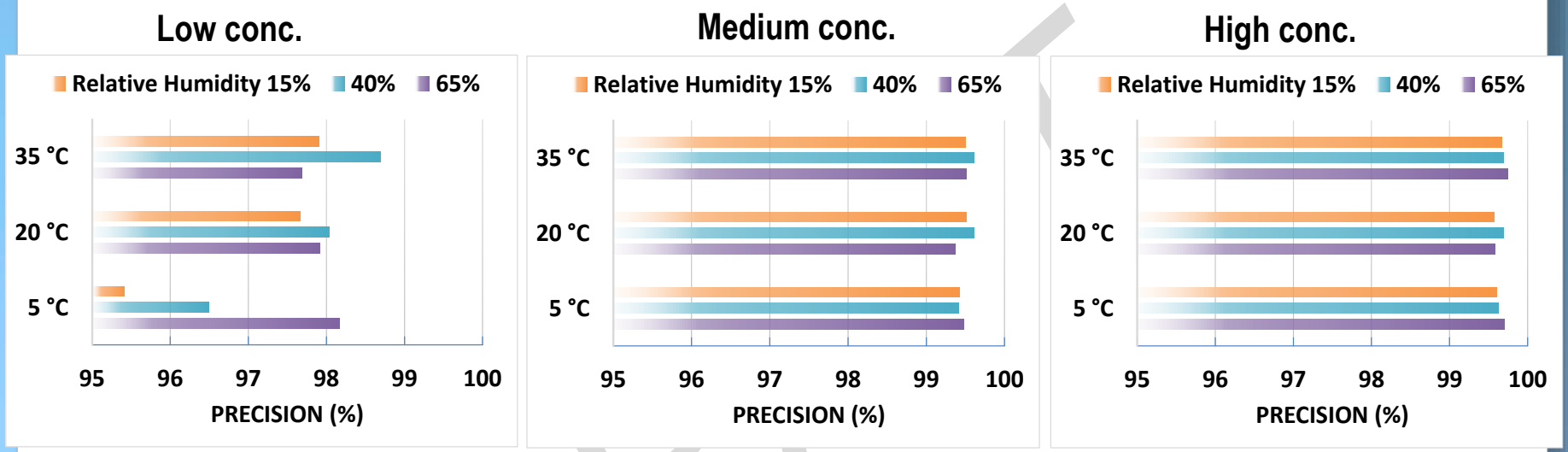
- The PurpleAir PA-II sensors showed good accuracy compared to GRIMM PM_1 over the concentration range of 0-175 $\mu g/m^3$ at 20 °C and 40% RH. PA-II sensors had better accuracy (85-95%) at lower PM_1 concentration (10-30 $\mu g/m^3$). PurpleAir PA-II sensors' accuracy decreased to ~70% when PM_1 mass conc. was between 70-175 $\mu g/m^3$.

PA-II Data Recovery and Intra-model variability

- Data recovery for PM_1 mass concentration from 8464a, cc53a, and b688a were 95.9%, 96.6%, and 96.7%.
- Low PM_1 measurement variations were observed among the three PA-II units.

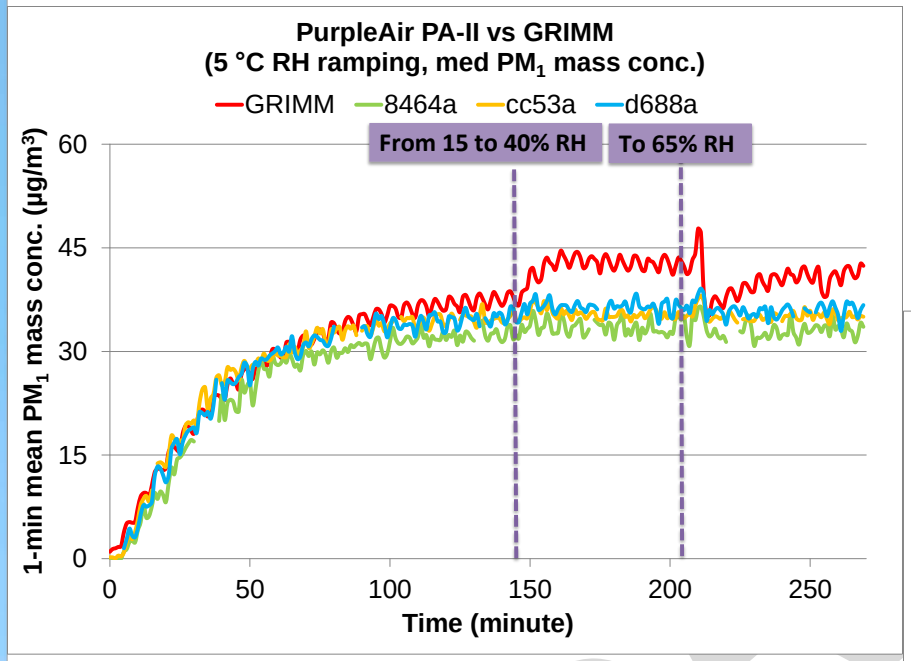
PM_1 Precision: PurpleAir PA-II

- Precision (Effect of PM_1 conc., Temperature and Relative Humidity)

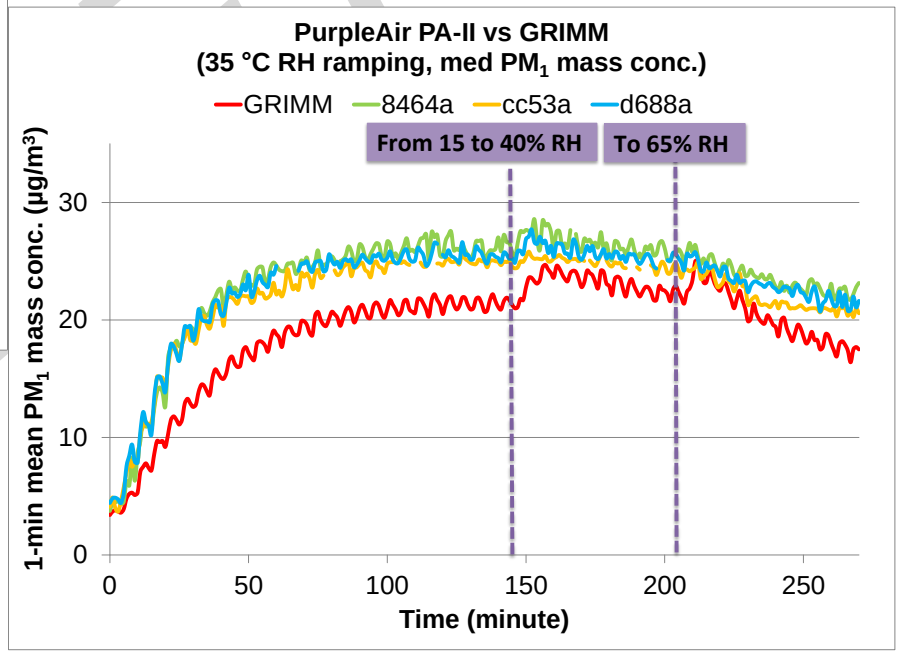


- Overall, the three PA-II sensors showed high precision for most of the combinations of low, medium and high PM_1 conc., T, and RH.
- At low PM_1 mass conc. and 5 °C/15% RH, precision was lower for both the sensors and the GRIMM.

PurpleAir PA-II Climate Susceptibility



Low Temp - RH ramping
(medium conc.)

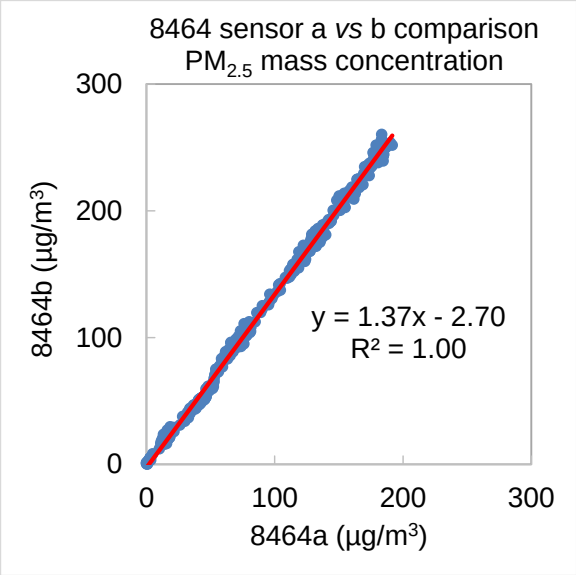


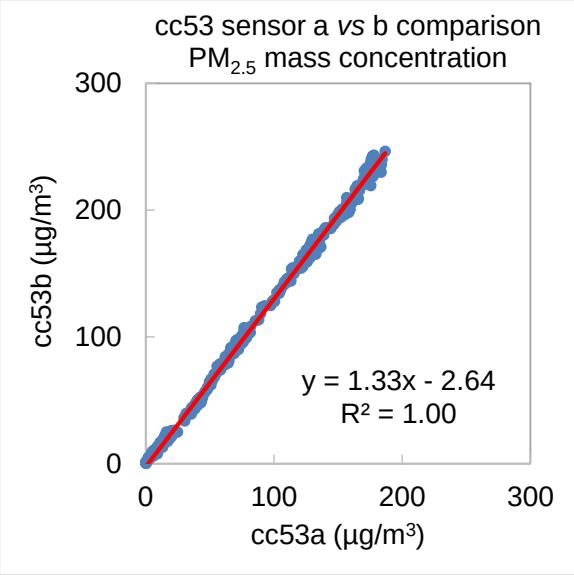
High Temp - RH ramping
(medium conc.)

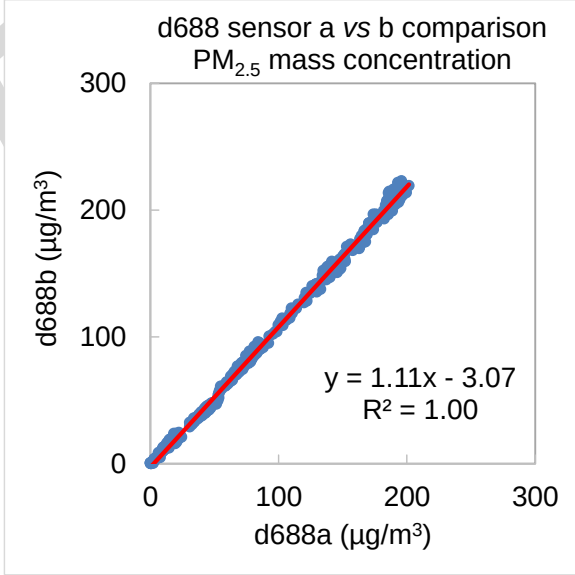
Evaluation results for PurpleAir PA-II $PM_{2.5}$ mass concentration

PurpleAir PA-II vs FEM GRIMM

sensor *a* vs *b* comparison

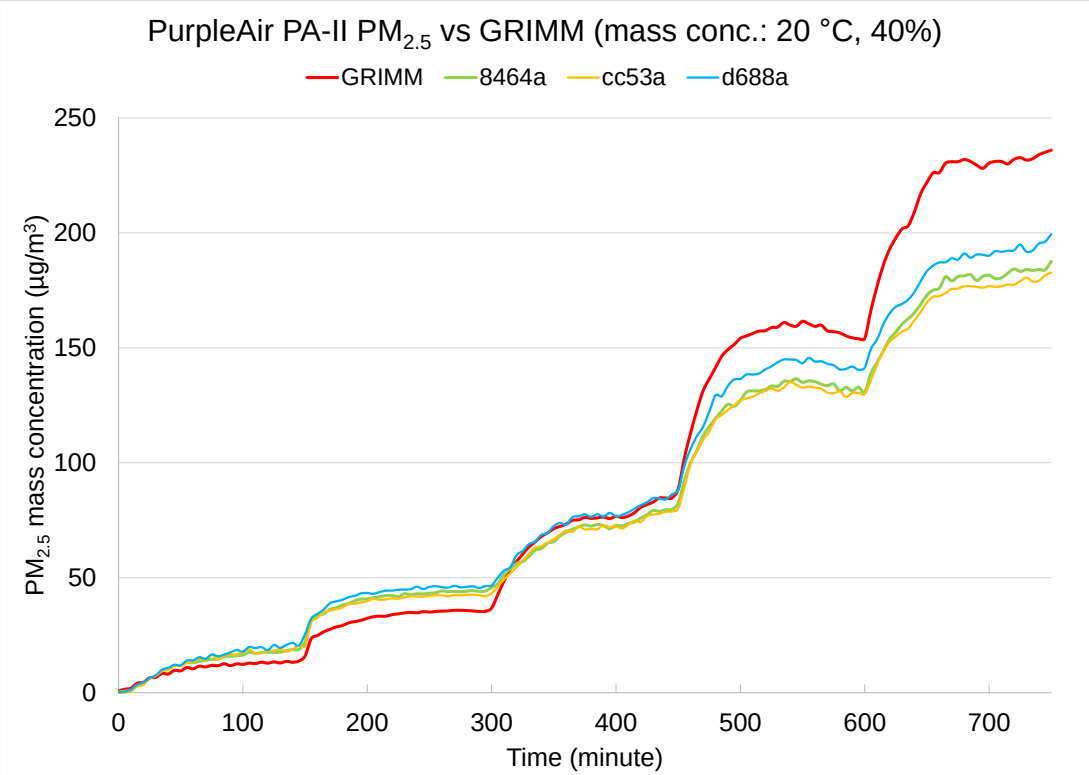






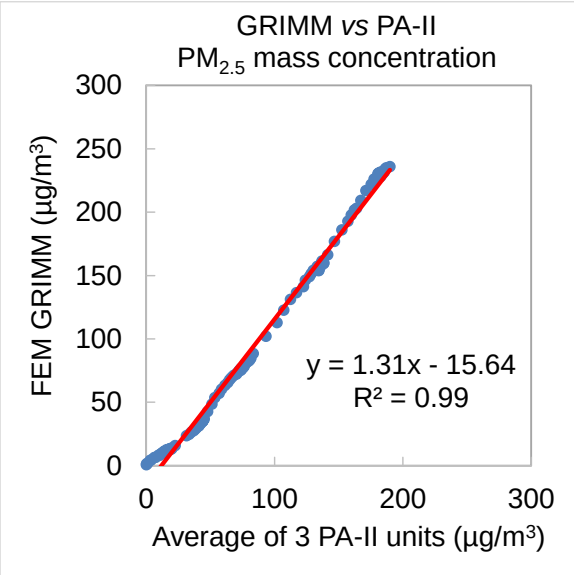
- PurpleAir PA-II contains two raw sensors in each unit, denoted *a* and *b*. For a PM concentration ramping experiment, sensor *a* and sensor *b* had excellent linear correlation with $R^2 > 0.99$.
- However, sensor *b* reported 11-37% higher $PM_{2.5}$ mass concentration than sensor *a* did.
- In order to strictly follow the AQ-SPEC laboratory evaluation protocol, only data from the three *a* sensors is considered in determining evaluation parameters.

PA-II vs FEM GRIMM ($PM_{2.5}$ mass; 5-min mean)



- Over the full $PM_{2.5}$ concentration range tested (0-250 µg/m^3), the three PA-II sensors tracked well with the concentration variation recorded by FEM GRIMM.

Coefficient of Determination



- Three PA-II sensors showed excellent correlation with GRIMM $PM_{2.5}$ mass conc. (R^2 > 0.99) between 0-250 µg/m^3.
- PA-II sensor underestimated the GRIMM $PM_{2.5}$ mass conc.

$PM_{2.5}$ Accuracy: PA-II vs FEM GRIMM

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean ($\mu g/m^3$)	GRIMM ($\mu g/m^3$)	Accuracy (%)
1	19.7	13.5	54.3
2	44.3	35.7	75.7
3	80.8	84.1	96.1
4	134.7	155.1	86.8
5	186.3	233.5	79.8

- The three PA-II sensors showed moderate to good accuracy (54.3-96.1%) compared to FEM GRIMM $PM_{2.5}$ over the concentration range tested (0-250 $\mu g/m^3$).

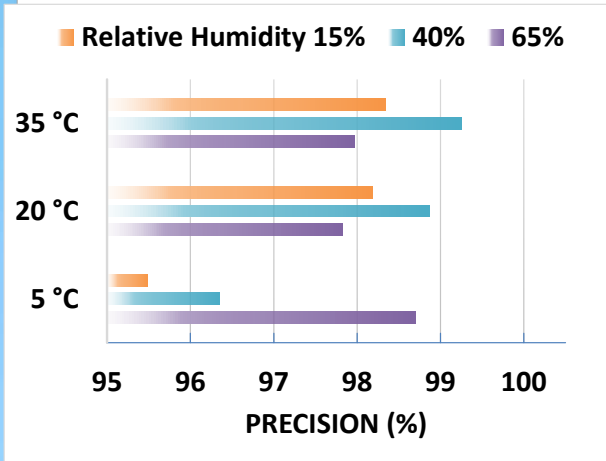
PA-II Data Recovery and Intra-model variability

- Data recovery for $PM_{2.5}$ mass concentration from 8464a, cc53a, and b688a were 96.1%, 96.6%, and 96.1%.
- Low $PM_{2.5}$ measurement variations were observed among the three PA-II sensors.

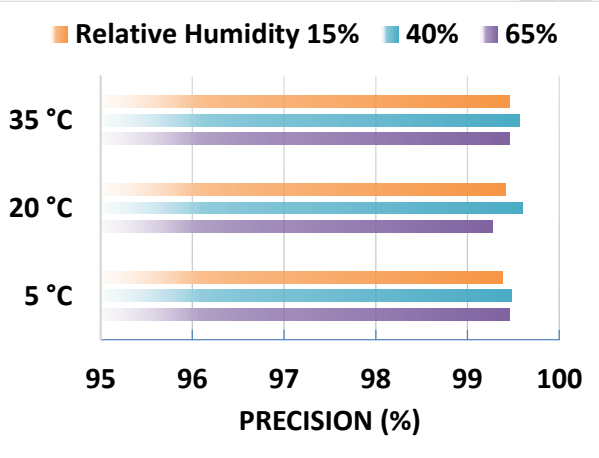
$PM_{2.5}$ Precision: PurpleAir PA-II

- Precision (Effect of $PM_{2.5}$ conc., Temperature and Relative Humidity)

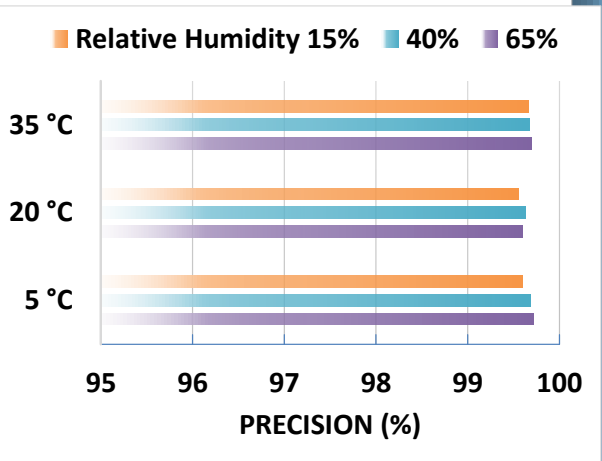
Low conc.



Medium conc.

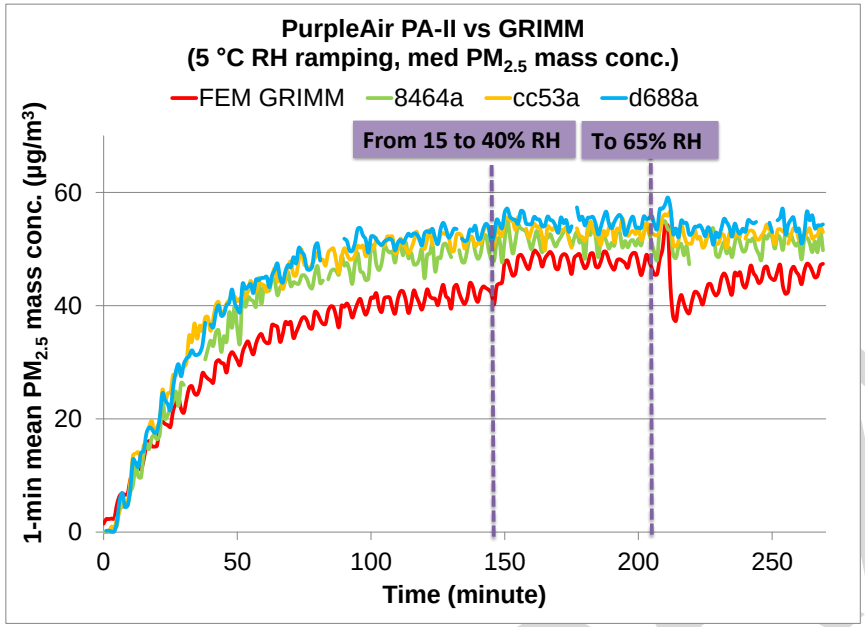


High conc.

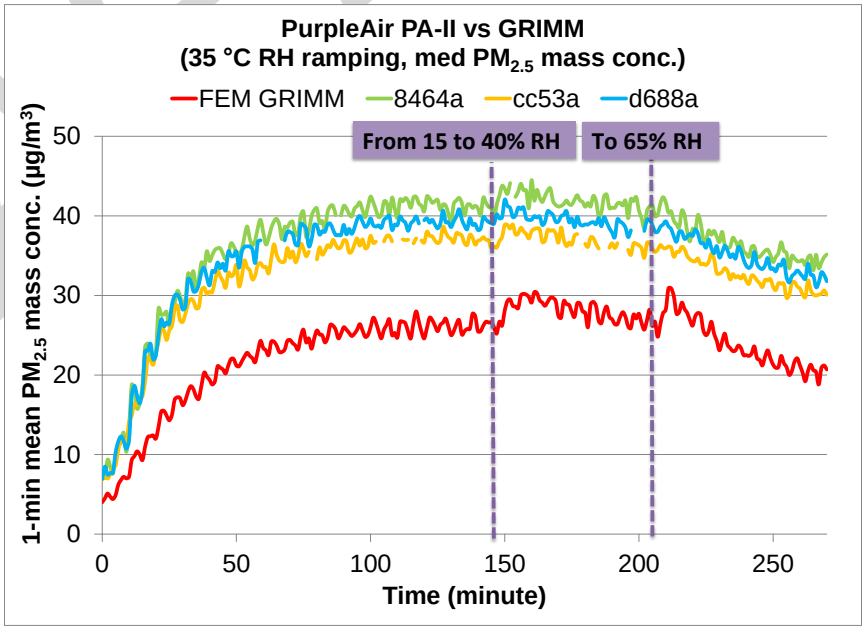


- Overall, the three PA-II sensors showed high precision for most of the combinations of low, medium and high $PM_{2.5}$ conc., T, and RH.
- At 5 °C/15% RH, 5 °C/40% and low $PM_{2.5}$ mass conc., precision was lower for both the sensors and the GRIMM.

PurpleAir PA-II Climate Susceptibility



Low Temp - RH ramping (medium conc.)



High Temp - RH ramping (medium conc.)

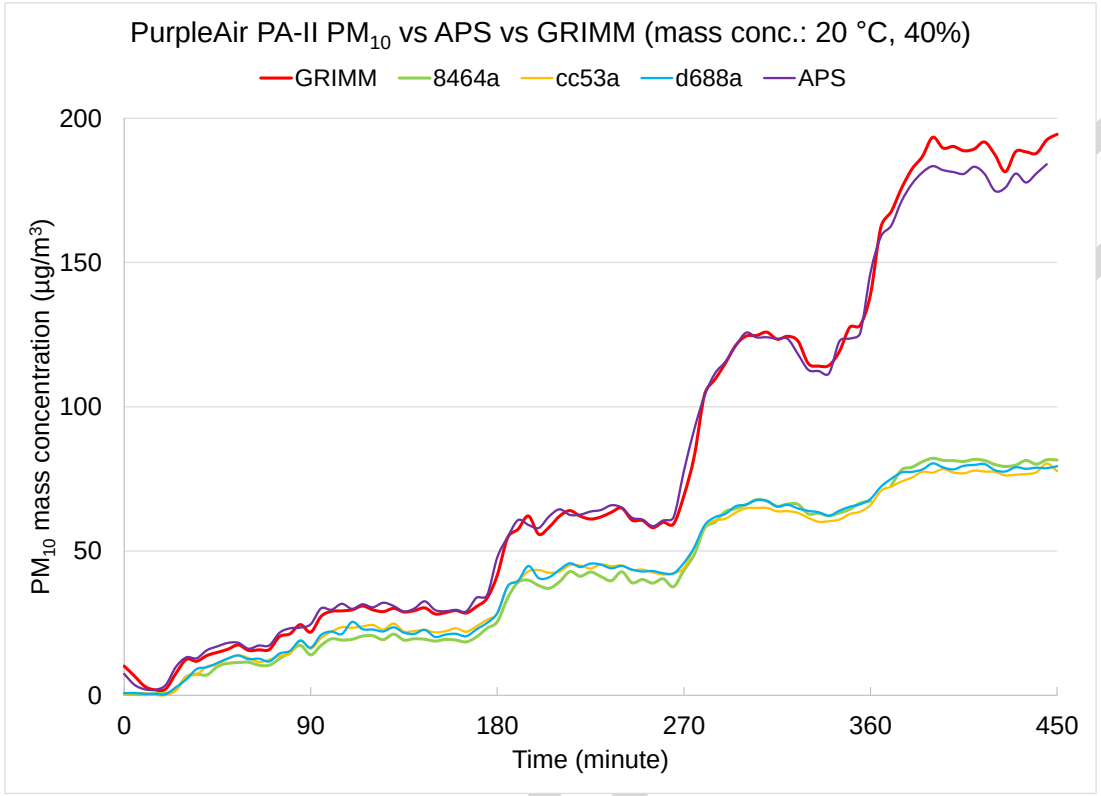
Discussion (PM_1 and $PM_{2.5}$)

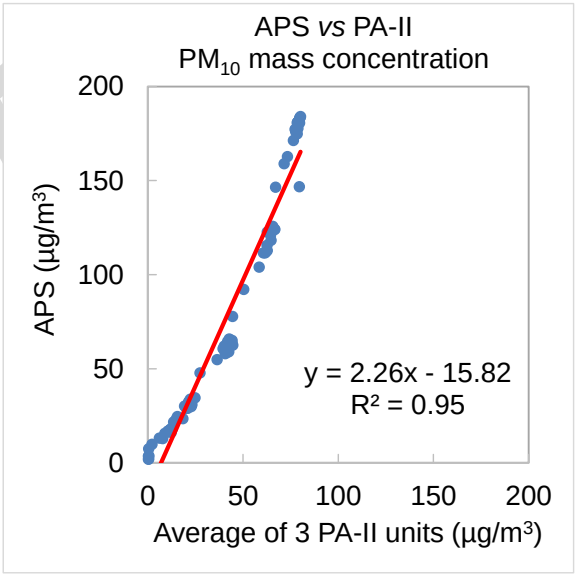
- **Accuracy**: Overall, the three PA-II sensors have moderate to good accuracy, compared to GRIMM PM_1 and $PM_{2.5}$ in the range of 0 to 250 µg/m^3.
- **Precision**: The three PA-II sensors have high precision for most of the test combinations (PM concentrations, T and RH).
- **Intra-model variability**: Low intra-model variability was observed among the three PA-II sensors.
- **Data Recovery:** Data recovery for PM_1 mass concentration from 8464a, cc53a, and b688a was 95.9%, 96.6%, and 96.7%. Data recovery for $PM_{2.5}$ mass concentration from 8464a, cc53a, and b688a was 96.1%, 96.6%, and 96.6%.
- **Linear correlation**: The three PA-II sensors showed very good correlation/linear response with the corresponding GRIMM PM_1 and $PM_{2.5}$ measurement data ($R^2 > 0.99$) for mass concentration range between 0 and 250 µg/m^3.
- **Climate susceptibility**: For most of the temperature and relative humidity combinations, the climate condition had minimal effect on the PA-II's precision. At the set-points of RH changes at low PM concentrations, PA-II sensors had some spikes.

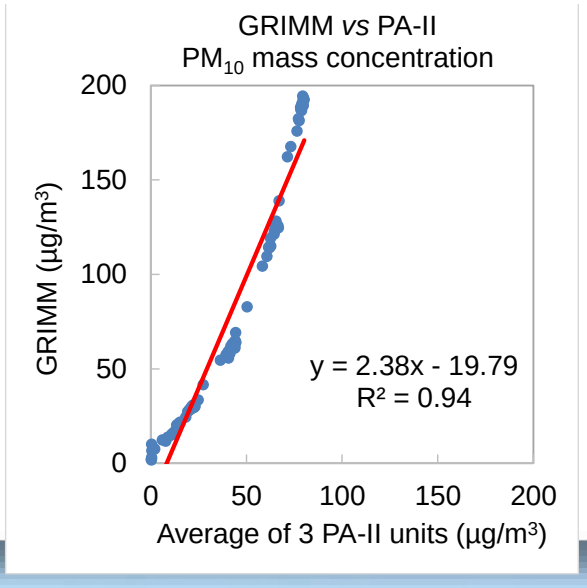
Evaluation results for PurpleAir PA-II PM_{10} mass concentration

PurpleAir PA-II vs GRIMM vs APS

PA-II vs APS vs GRIMM (PM_{10} mass; 5-min mean) Concentration ramping at 20 °C, 40% RH







- Over the full PM_{10} concentration range tested (0-200 µg/m^3 as measured by APS using 2.6 g/cm^3), the three PA-II sensors tracked well the conc. variation as recorded by the APS and GRIMM.
- The PA-II sensors underestimated the PM_{10} mass concentration measured by APS and GRIMM, especially at higher concentration.

PM_{10} Accuracy: PA-II vs APS vs GRIMM

- Accuracy (20 °C and 40% RH)

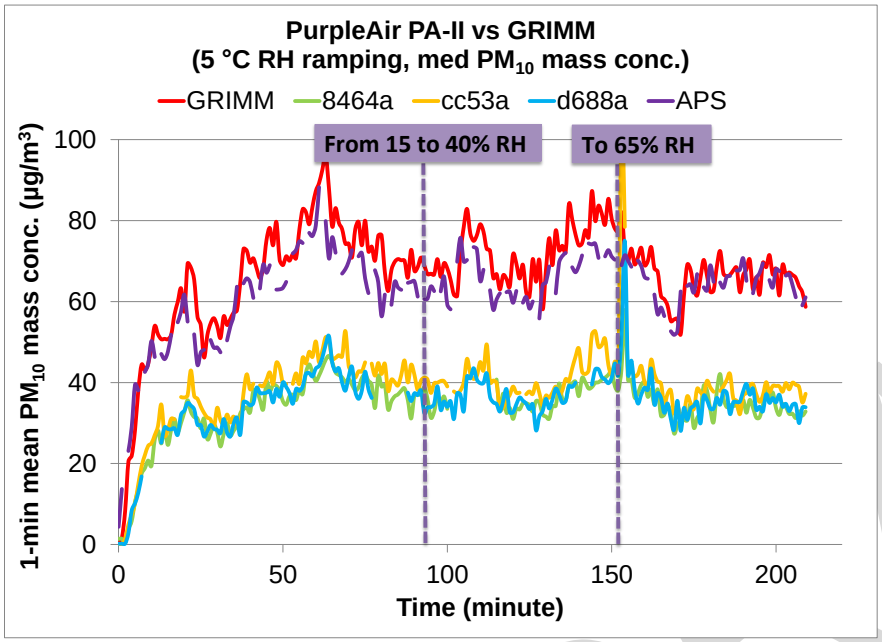
Steady State (#)	Sensor mean (µg/m³)	APS-2.6 (µg/m³)	Accuracy (%)	Steady State (#)	Sensor mean (µg/m³)	GRIMM (µg/m³)	Accuracy (%)
1	13.8	21.4	64.5	1	13.8	19.0	72.7
2	21.7	31.8	68.3	2	21.7	30.0	72.2
3	41.8	60.4	69.2	3	41.8	60.4	69.3
4	63.3	120.9	52.4	4	63.3	120.3	52.7
5	78.8	178.7	44.1	5	78.8	188.0	41.9

- The three PA-II sensors had moderate accuracy (44%-73%) when compared to APS and GRIMM. As PM_{10} concentration increased, sensors' accuracy decreased. Sensors underestimated PM_{10} concentration as measured by APS and GRIMM.

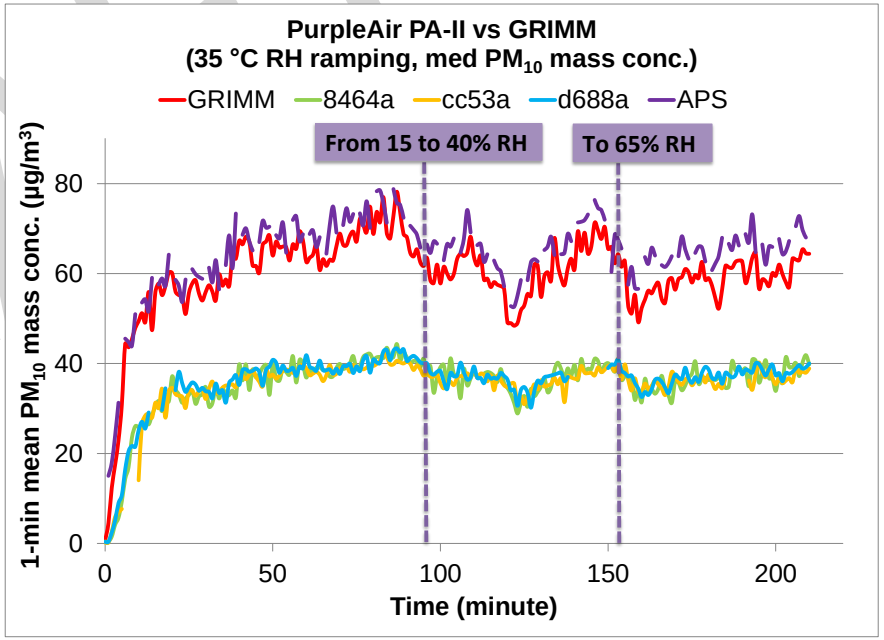
PA-II Data Recovery and Intra-model variability

- Data recovery for PM_{10} mass concentration from 8464a, cc53a, and b688a were 94.4%, 93.2%, and 94.0%.
- Low PM_{10} measurement variations were observed among the three PA-II sensors.

PurpleAir PA-II Climate Susceptibility



Low Temp - RH ramping
(medium conc.)



High Temp - RH ramping
(medium conc.)

Discussion (PM_{10})

- **Accuracy**: The three PA-II sensors had moderate accuracy (44%-73%) when compared to APS and GRIMM. As PM_{10} concentration increased, sensors' accuracy decreased. Sensors underestimated PM_{10} concentration as measured by APS and GRIMM.
- **Precision**: Due to the nature of Arizona test dust, the aerosol concentration showed some variability, therefore, the precision cannot be fairly estimated. As observed in the climate susceptibility experiments, APS and GRIMM showed higher sensitivity to the aerosol concentration changes than the three PA-II sensors did.
- **Intra-model variability**: Low intra-model variability was observed among the PA-II sensors.
- **Data Recovery:** Data recovery for PM_{10} mass concentration from 8464a, cc53a, and b688a were 94.4%, 93.2%, and 94.0%.
- **Linearity of sensor response**: PA-II sensors showed good correlation/linear response with the corresponding APS PM_{10} (R^2 = 0.95) and GRIMM PM_{10} (R^2 = 0.94).
- **Climate susceptibility**: From the laboratory studies, temperature and relative humidity had minimal effect on the PA-II sensors' performance. At the set-points of RH changes, units reported spiked changes in concentrations.